Universe as a Phase Boundary in a Four-Dimensional Euclidean Space

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Abstract

It is proposed that space is a four-dimensional Euclidean space with universal time. Originally this space was filled with a uniform substance, pictured as a liquid, which at some time became supercooled. Our universe began as a nucleation event initiating a liquid to solid transition. The universe we inhabit and are directly aware of consists of only the three-dimensional expanding phase boundary. Random energy transfers to the boundary from thermal fluctuations in the adjacent bulk phases are interpreted by us as quantum fluctuations. Fermionic matter is modeled as screw dislocations; gauge bosons as phonons. Minkowski space emerges dynamically through redefining local time to be proportional to the spatial coordinate perpendicular to the boundary. Other features include a geometrical quantum gravitational theory, and an explanation of quantum measurement.

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In the following, a new picture of the big bang and the underlying structure of the universe is proposed, based on a classical field theory in four-dimensional Euclidean space with a universal time (a 4+1 dimensional theory). The big bang is treated as a nucleation event for a first-order phase transition (pictured as a liquid to solid transition) and our universe is the three-dimensional phase boundary between the expanding solid and preexisting liquid phases. This classical theory appears to be able to explain a diverse set of phenomena – the expansion of the universe at a non-decreasing rate, special relativity (which arises dynamically from the expanding phase boundary), quantum fluctuations in terms of four-dimensional thermal fluctuations, quantum measurement in terms of classical spontaneous symmetry breaking, and a quantum theory of gravity based on the geometry of the expanding hypersurface. The specific model of a growing crystal allows one to model elementary fermions as screw dislocations and bosons as phonons. Collisions with other universes provides possible explanations for the pattern of matter distribution in the universe and for the existence of quasars.

We begin by assuming a four-dimensional Euclidean space, filled with a uniform fluid at some temperature, undergoing thermal fluctuations. In addition to the four spatial dimensions, there is also a universal time. Another possibility would be to start with a five-dimensional Minkowski space. This liquid was cooling, became supercooled, and at some point a solid crystal nucleated. This was the big bang. The universe begins as a fluctuation, already at a finite size, because in order to grow rather than shrink, the initial crystal must be large enough that the positive surface energy is less than the negative volume energy relative to the liquid. The *surface* of the solid, the phase boundary, is an expanding three-dimensional space, our universe. This differs from other "bubble universe" pictures, where the universe is the *interior* of a *3-d* bubble. We are not directly aware of the relatively uniform liquid and solid phases, but only of the phase boundary between them, which we refer to as the "present". As the crystal grows, this hypersurface, our universe, expands. Already there is a variance with the usual $\Lambda = 0$ Friedmann universes. Namely, our universe is closed, but will expand forever. The pressure on the surface caused by the energy difference of the two phases acts like a repulsive cosmological constant. This universe actually expands faster as time goes on, not slower. If dissipation is present it will eventually approach a constant rate. (This assumes a constant amount of supercooling – if the base liquid cools more, the expansion rate could continue to increase as the degree of supercooling increases. Without dissipation, the expansion rate increases exponentially). Recent astrophysical evidence shows that the expansion rate is not slowing, but may even be speeding up[1] which is consistent with this scenario.

The basic theory needed to describe this expanding phase boundary is non-equilibrium classical statistical mechanics. The solid, in some sense, lies in the past, since we have been there earlier, although it still exists in the present when observed from the higher dimension. The liquid represents the future, since that is where we are going, but it also exists now, as an undifferentiated, fluctuating medium. To distinguish the current states of the solid and the liquid from our own past and future, they may be called the "current past" and "current future". They differ from our past and future because changes may have occurred after the solid was formed, and

the future certainly will be different when we arrive there. To the extent that the solid is frozen, however, our past may be accurately preserved within it. We may not be aware of the existence of the liquid due to its uniformity. However, the boundary which we inhabit is in thermal contact with both the liquid and solid phases, and can certainly exchange energy with them. Thus objects riding the interface will get random energy fluctuations from this thermal contact. These random thermal fluctuations could explain quantum fluctuations. It is well known that in ordinary quantum theory, if Minkowski space is analytically continued to Euclidean space, quantum fluctuations behave as higher-dimensional thermal fluctuations, i.e. the Feynman path integral becomes an ordinary statistical mechanical partition function in 4 (+1) dimensions. Plank's constant is proportional to the temperature of the four-dimensional Euclidean space. In such a picture a quantum phenomenon such as tunneling is explained classically as due to a random kick of extra energy which results from thermal contact with the liquid and solid phases. Due to such thermal fluctuations, energy is not conserved over short time periods; it is conserved only in the average over time.

Usually, analytic continuation to Euclidean space is seen as a mathematical trick to transform the poorly-defined physical Minkowski-space theory into a Euclidean-space partition function that is easier to handle. Here, it is proposed that Euclidean space *is* the correct physical space. It is Minkowski space which results from a mathematical trick designed to describe a decidedly non-equilibrium feature, the expanding phase boundary, within the formalism of equilibrium statistical mechanics. In single-phase equilibrium statistical mechanics, correlation functions decay exponentially with distance or time. However, a feature like an expanding phase boundary propagates without decaying. One way to represent such a feature is to give it an imaginary energy, which produces a pole in the Fourier transform of the correlation function. To keep time as the Fourier conjugate of energy, it must also be taken imaginary. In this way, nondecaying features can be modeled within equilibrium statistical mechanics, by just the inverse of the trick often used to allow particle decay in quantum mechanics. This "mathematical trick" results in a Minkowski space in the "*ict*" formulation. If observers in the hypersurface choose their local time coordinate to be proportional to the fourth spatial coordinate perpendicular to their expanding 3-d hypersurface, special relativity can be fully realized. This time is equal to the product of universal time and the expansion rate for observers co-moving with the expansion.

Since the background theory is a classical field theory undergoing a phase transition one does not have to use methods borrowed from equilibrium physics – in fact it is not entirely correct to do so. A purely non-equilibrium approach involving, say, the Langevin equation, may be better. The universe, evolving with universal time, is in a definite state at any time. However, 4-d thermal fluctuations may create a kind of zitterbewegung – very rapid variation at small scales, that enforces the uncertainty principle. This more classical evolution affords the opportunity to explain the quantum measurement process as a spontaneous symmetry breaking event[2]. A measuring device, originally with an unbroken symmetry, couples to a system under study becoming strongly correlated with it. Then an adjustment is made to the potential of the measuring device which initiates spontaneous symmetry breaking. The mea-

surement takes place at this time, when the ensemble of possible future states of the combined system splits into non-ergodic subensembles corresponding to the possible values of the order parameter, also corresponding to possible values of the measured quantity. Future evolution is confined to a single subensemble in the usual manner of a classical symmetry-breaking phase transition. In this picture measurements are well defined, the collapse is a physical event, and a clear distinction exists between what constitutes a measuring device and what does not. Because the "current past" is continuously undergoing 4-d thermal fluctuations, it is only frozen to the extent that the ensemble is limited due to spontaneous symmetry breaking. Thus questions such as "which slit did the electron go through" or "which direction was the spin pointing" are as meaningless here as they are in standard quantum mechanics. This is because the details of history are continuously being rewritten as the current past fluctuates. Only to the extent that the ensemble is limited by spontaneous symmetry breaking can one make definite statements about past events.

Using a crystal as the analogy for the "current past" phase affords the possibility of describing fermions as screw dislocations. These obey an exclusion principle and have long range forces with left/right-hand acting like particle/antiparticle. They can annihilate or be pair produced. Screw dislocations in an ordinary three-dimensional crystal form line defects. In a four-dimensional crystal such dislocations have a sheet topology, thus the basic material entity would actually be a fermionic string. The embedding of such an object into the crystal is rather complex, and may contain enough structure to explain both spin and isospin. This is because the O(4) rotational symmetry of 4-d space can be written as SU(2) $\times$ SU(2). The interface could also allow (or actually require) the use of domain-wall fermions, one method of obtaining a chiral theory[3]. It should also be pointed out that dislocations are a wave phenomenon; essentially they are soliton-like displacement waves in the underlying crystal. Thus this can also be seen as a realization of the general idea of explaining fermions as solitons. Because they are waves, matter can and does exhibit interference phenomena in this theory.

Of course the solid-state analogy for the photon is the phonon. Phonons obey a relativistic-like dispersion relation, relative to the speed of sound. One can have phonons which travel only on the surface, as well as within the bulk phases. If sound speed in the crystal is to be equated with light speed, however, what happens to the faster-than-light prohibition of special relativity? It actually still holds for dislocations! It has been shown that screw dislocations cannot move faster than the speed of sound in the medium. Their effective mass from the stress in the surrounding crystal grows with speed, becoming infinite as the speed of sound is approached, in an exact mathematical analogy with the relativistic mass increase[4]. These dislocations also experience a Lorentz-like length contraction relative to the speed of sound, also following exactly the mathematics of a Lorentz transformation. This curious mathematical analogy between the behavior of dislocations in crystals and the special theory of relativity was first noted by Frenkel and Kontorowa in 1938[4]. What is being suggested here is that this is perhaps not just an analogy, but the actual explanation for the Lorentz transformation. This is reminiscent of the original viewpoint of Lorentz and Fitzgerald, that the contraction is a dynamical physical effect. If a universal time is used, then one would have an ether theory with a preferred

frame, the rest frame of the medium, in contradiction with the Michelson-Morley experiment. The Lorentz transformation would work in only one direction, because it would be missing the time part of the transformation. However if each observer chooses a time coordinate along their own world line, a fully reciprocal special relativity based on the speed of sound as limiting velocity can arise. This is because the operation of any moving clock constructed from matter will be affected by the length-contraction and mass increase effects in such a way that it runs slow compared to a stationary clock. In other words, the usual relativistic time dilation can be derived as a consequence of the length-contraction and mass increase (for a specific model clock one can take a mass-spring oscillator, a "light clock" consisting of light bouncing between mirrors constructed with material spacers, or other simple physical systems). The combination of a time-dilated clock and a tilted time axis (along the observer's world line) results in the correct Lorentz time transformation. Thus if the moving observer chooses this as the time coordinate, a theory exactly equivalent to special relativity arises, and the effects of moving with respect to the ether are effectively hidden from the moving observer (of course in our material world there are methods even in standard special relativity of determining the preferred frame at rest with the expansion - it is the frame in which the temperature of the cosmic background radiation is isotropic).

In this theory, special relativity is a dynamical effect, not a property of the underlying space, but of the *particular* solution of an expanding phase boundary, together with our identification of the passage of time with our motion in the fourth spatial direction as a result of the expansion. The usual logic of special relativity is turned around. Length-contraction and mass-increase are the basic phenomena, from which time-dilation, the full Lorentz transformation, and finally the apparent constancy of the speed of light for all inertial observers (the usual main postulate of special relativity) is derived (this last as a consequence of the full Lorentz transformation).

A more geometrical, but less complete argument for the origin of Minkowski space is as follows. Two observers share a common Euclidean metric in the background space,

$$ds^2 = dx_1^2 + dx_2^2 + dx_3^2 + dx_4^2 = ds'^2 = dx_1'^2 + dx_2'^2 + dx_3'^2 + dx_4'^2.$$

The direction x_4 is the expansion direction for the unprimed observer, x_4' that of the primed observer (i.e. along that observer's direction of motion). Assume each analytically continues their fourth coordinate to imaginary values, $t = ix_4$ and $t' = ix_4'$, in order to model the non-decaying phase front as explained earlier. Then the metric becomes

$$ds^2 = dx_1^2 + dx_2^2 + dx_3^2 - dt^2 = ds'^2 = dx_1'^2 + dx_2'^2 + dx_3'^2 - dt'^2.$$

and the observers feel they are living in a 3+1 dimensional Minkowski space.

Although material objects cannot exceed the speed of sound, the phase front itself can expand faster than the speed of sound, as in a detonation. This may be necessary to isolate us from waves sent into the past that reflect back, which does not seem to accord with experience.

Variations in the geometry of the expanding hypersurface lead to the possibility of a general-relativity like gravitational theory, but which would naturally include

quantum fluctuations as 4-d thermal fluctuations. Interestingly, crystal growth is faster near dislocations, which would distort the local surface geometry in regions where dislocations are concentrated; matter could affect curvature by this mechanism. This theory would differ from general relativity, but might be approximated by it. It is interesting to speculate what black holes would look like in this picture. They would be stalagmite-like protuberances from the base crystal, with sides sloped at an angle greater than 45°. Surface phonons would be non-propagating due to an expansion rate faster than the speed of sound. But other than this, the interior of the black hole would not be so different from the exterior, and there would not seem to be a need for a singularity.

It is also interesting to consider the possibility of collisions between two such universes. This can be envisioned as similar to two soap bubbles colliding and then coalescing, except that it needs to be pictured in one more dimension. The intersection of two three-dimensional surfaces is a two-dimensional surface. The "grain boundary" that would form at the intersection would be full of dislocations. This could explain why matter in the universe appears to exist mostly in 2-d wall-like features. In this scenario, most matter would not have been created in the initial big bang, but in one or more cosmic collisions shortly thereafter with other growing universes that nucleated nearby. Matter would never have existed in a homogeneous distribution, but rather would be created in a clumpy distribution. This would make galaxy formation easier, but might not be able to adequately explain the uniformity of the cosmic background radiation. If the nucleation events were heterogeneous, it is possible to have a number of correlated nucleations to occur near one another in space and time, but be rare in other regions. After an initial series of collisions, the coalesced universes can then grow undisturbed into a quieter region of the pure liquid phase. This could explain why such collisions do not appear to be occurring today. Collision of our universe with a smaller universe would be quite spectacular. One would see a rapidly expanding shell, the collision boundary, which would at first expand at superluminal velocity (this is due to the geometry of the collision - even the join-radius of two fast-moving colliding soap bubbles could expand superluminally because no actual matter is travelling superluminally). This would also be a locus of matter formation and emit copious radiation. If the colliding universe were also rotating with respect to ours, then one handedness of dislocations would predominate over the other, giving a possible reason for the preponderance of matter over antimatter. That part of our universe that existed previously within the shell would be utterly destroyed (as would the corresponding part of the other universe). These regions would no longer reside on the surface, but would now be in the interior of the crystal, buried in the past. What would finally exist inside the expanding spherical shell (which would eventually slow down and stop) would be the entire other universe, patched into our own. It is interesting to speculate that quasars could be the result of such collisions with other small universes. Many quasars appear to have superluminal velocities or correlations within them[5], though conventional explanations may be able to explain these as essentially optical illusions.

The expanding phase-boundary model also has good explanations for the horizon and flatness problems. Since the universe presumably preexisted for a long time before the initial nucleation event, there was plenty of time for causal contact to

be established. The relative flatness is explained by the automatic “fine-tuning” that occurs at a phase transition. The phase surface will grow only at the correct temperature.

Clearly much work remains to be done. A correct base theory for the 4(+1)-dimensional Euclidean space needs to be found that would reproduce both the standard model and General Relativity (or generalizations of these) on the 3(+1)-dimensional expanding phase boundary. The model is intriguing in its common-sense (i.e. classical) explanations for the origin and expansion of the universe, the source of quantum fluctuations, and the mechanism of quantum measurement, as well as the possibility of a fully-quantum gravitational theory. The modeling of fermions as screw dislocations and photons as phonons is also intriguing, but not a necessary part of the basic expansion model. For instance, another possibility could be that the transition is more akin to that between a normal fluid and a superfluid, with fermions modeled as vortices - or it could bear little resemblance to any previously known phase transition from liquid or solid-state physics. Although this theory is far from complete, which is difficult at the outset for such a wide-ranging idea, it is hoped that this outline will spark further ideas that may someday form a viable alternative to or enhancement of standard big-bang cosmology.

References

[1] A. Reiss et. al., astro-ph/9805201, Astronomical Journal, to appear; S. Perlmutter et. al., Nature, **39** (1998) 51; P.M. Garnavich et. al., Ap. J., **493** (1998) L53.

[2] G.T. Zimányi and K. Vladár, Phys. Rev. A **34** (1986) 3496, Found. Phys. Lett. **1** (1988) 175; M. Grady, SUNY-FRE-94-05, hep-th/9409049 (unpublished).

[3] D. B. Kaplan, Phys. Lett. B **288** (1992) 342.

[4] F.C. Frank, Proc. Phys. Soc. **A62** (1949) 131; J. Frenkel and T. Kontorowa, Phys. Z. Sowjet **13** (1938) 1; for a modern reference see J. Weertman and J.R. Weertman, Elementary Dislocation Theory, NY, Oxford U. Press (1992), p40.

[5] T. J. Pearson et. al., Nature, **290** (1981) 365.